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Application of Interactive Multiple Goal Programming Techniques for Analysis and Planning of Regional Agricultural Development

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SUMMARY

This paper describes a method of investigating development possibilities for a region under various constraints and demands. Use is made of an interactive multiple goal linear programming technique. The method is illustrated with an example from a semi-arid zone in the Mediterranean Basin. It is concluded that the method can help to decide on feasible development pathways within a wide range of technical and socio-economic scenarios, and so explore the 'margins for policy'. It enables communication between politics, planning and research and can therefore serve as a tool for more efficient development planning.

1 INTRODUCTION

Agricultural development is undertaken to satisfy a number of socio-economic goals. These include increased production, employment and profit, as well as other goals like environmental stability, pollution

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abatement and political compensation. Regional agricultural development is, as a rule, dependent on import of inputs from and export of outputs to other regions and sectors of the economy. In order to plan effectively, it is necessary to answer questions like: What is the agricultural potential of a region? Which production techniques are available for crops and livestock? What are the inputs required to realize the production potential offered by these techniques? Under what socio-economic conditions is it attractive to practise them? Is there scope for improved techniques that have not yet been applied in the region? Does their application require more research?

The answers to these questions depend not only on the technical potentials in a region, but also on the goals of development. The emphasis on different goals will influence the choice of techniques, the pathway of development and the research priorities. Whatever plan is finally adopted, it must be technically feasible to be effective. A feasible development plan must consider all the goals imposed on the region. Different feasible development pathways that satisfy different goals are often possible and the 'trade-offs' between goals determine the degree of accommodation possible between different interest groups. The planning policy adopted will reflect, implicitly or explicitly, the relative importance of the different goals. On the other hand, analysis of the implications of a given policy can be used to modify that policy so as to arrive at a more favourable balance of goal achievement.

In this paper a method is described to investigate to what extent the fund of techniques that is available for a region can meet the demands that may be put on it by the stakeholders in its development. It explores feasible development pathways for a region under various constraints and demands, while the input requirements and the investment needs are quantified.

2 THE METHOD

The method used is based on a multiperiod linear programming approach that optimizes a mix of production processes over a development period, subject to a set of constraints. The production processes are defined as 'activities', each with its set of inputs and related outputs. The objective function to be optimized can be any of the outputs or inputs.

The inputs draw on regional resources which are limited and can constrain the choice of the production processes. When only one goal is to be optimized, the linear programming problem is straightforward. However, when a number of goals have to be optimized, some of them conflicting, the choice for a certain development path becomes dependent on the importance attached to each of the goals. The importance of each goal will not necessarily be the same for different policy makers and interest groups.

This situation prompted the development of a method known as Interactive Multiple Goal Linear Programming (Spronk & Veeneklaas, 1983).

The interactive approach requires that the desired solution is attained at the end of a series of iteration cycles. In the first cycle, the lower bounds of all goals that are considered, are set at their minimum values to ascertain that feasible solutions are obtained that satisfy all these minimum requirements at the same time. Then each of the goals is maximized on its own, with the lower bounds of the other goals defined as minimum goal restrictions. On the basis of the results of this first iteration it may thus be concluded that for each of the goals no better value can be obtained than calculated in this iteration, and that for each of the goals it is not necessary to accept a value less favourable than its minimum goal restriction generated in this cycle. The solution space ('the feasible region') is defined in this way, but the Utopia where all the goals reach their maximum value simultaneously does not exist. Now, more satisfactory solutions, from the point of view of the 'user', may be obtained in subsequent iteration cycles by tightening one of the goal restrictions and repeating the iteration cycle for the other goals. The choice of the goal restrictions and the degree to which they are tightened, reflect the specific interests of the user. This stepwise maximization of the goals under increasingly tighter restrictions on the other goals reduces the solution space. In that way, the costs of satisfying one goal in terms of what must be sacrificed on the other goals is expressed. At last the user is faced with a solution space in which he cannot improve on any of his goals without sacrificing on another one, and where he has to make a choice. Hence, the user becomes aware of the possibilities of exchange between the various goals in his own solution space, i.e. he obtains the opportunity cost of one goal in terms of the other goals. Of course, users with different interests and aspirations are bound to end up in different corners of the initial solution space. This procedure uses a considerable amount of computer time. There are other methods of multiple goal programming that use less computer time, but usually at the cost of flexibility necessary for effective user interaction (Mendoza *et al.*, 1986; 1987).

When applied to regional analysis and planning in the field of agriculture, the input–output matrix contains 'all' existing and imaginable production techniques for the region, including those still in the R & D pipeline. These may include cropping activities, animal husbandry activities, and any other activities related to the agricultural sector. The coefficients for the matrix which quantifies the inputs and outputs for implementing and operating each activity, are obtained partly from crop growth simulation models and animal production models, especially when it concerns production techniques not yet practised in the region, partly from experimental results, and in part from statistical data. In addition, extensive use is made of the 'general body' of knowledge available from local experts to define the region properly. The coefficients in the matrix, for instance for cropping activities, define the yield and the inputs required to achieve that yield, such as season-specific fieldwork and material inputs such as water, fertilizer, and biocides. The fieldwork can be defined for various levels of mechanization, i.e. complete manual labour or the use of heavy machinery and its associated requirement for fossil fuel. The resources (or 'constraints') in the region define the right hand side (RHS) of the LP matrix and include the area and the quality of various land types available (land classes), the population living in the region, additional labour that may be hired from outside the region, endowment of capital goods, crop rotation constraints, animal breeds and herd sizes present in the region in the initial period, etc.

The expected technical life span of capital investment in land reclamation, building and equipment is another constraint that must be specified. The life expectancy of the breeding stock is accounted for in the definition of each activity that is based on animal production.

It is assumed that only goods and services that can be traded across the border of the region have prices. Thus, in general, no prices are attached to land or to labour of the local population, or to resources that cannot be easily transported, like bulky crop residues (straw) or aftermath grazing. Prices are attached to such goods as fertilizers, fencing materials, imported concentrates and products like grains and mutton. In this way the full range from completely closed (subsistence) to wide-open farming systems can be accommodated.

Because of linearity constraints relative prices cannot be generated endogenously by the model. That is not really a problem because internal prices do not play a role in the model and the regions that are considered are in general so small that the prices of tradeable goods are not affected by the production developments in the region. Subsidies on means of production can be treated by assuming availability of (limited quantities) of those goods at lower prices.

On the basis of the input–output matrix a multi-period linear program is developed to allow analysis of the dynamics of development (Spharim & Seligman, 1983). The multi-period mode makes it possible to investigate the investment requirements during the course of development and the effect of biological constraints such as the reproduction rate of animals.

Social constraints like ownership of the means of production, land titles, gender-specific labour quantities or little-ingrained economic behavioural patterns are not taken into account at first. Forced quantification of these aspects could block the perspectives for development at too early a stage. They may be introduced at a later stage to meet the subjective views of a particular user. Hence, the model does not 'predict' the future development of the region. It does define a feasible development pathway, that can best attain a set of goals if the necessary conditions are effective. It defines the required sequence of activities, investments, imports, exports, labour requirements, etc. As such, it can serve as a development plan for implementation or for policy making. How the plan must be implemented, or whether the techniques and resources will be available, will depend on many other factors. An example is the economic environment in which the activities take place, which has a direct bearing on the development possibilities of the region. The many characteristics of that environment are taken into account exogenously, very much in analogy to the climatic environment, that cannot be influenced by the farmer either. The model can be used to analyse the effects of different physical and economic scenarios and their effects on goal attainment. In this way it is possible to investigate to what extent the region, with the fund of techniques available, can meet the demands that may be put on it by governments, governmental or private agencies with interests in the region, farmers in the region or special interest groups. In terms of the model these demands are expressed as minimum acceptable goal restrictions.

To summarize: under the restrictions of the model, this interactive multiple goal optimization produces three types of results:

— it identifies consistent, technically-feasible development pathways for what is considered the most acceptable combination of goal values. This is of particular importance for systematically and effectively delimiting the full range of conceivable courses of development.
— it evaluates the cost of greater achievement of one goal in terms of the other goals and the model constraints. In that way technical bottlenecks and problems can be identified.
— it translates selected combinations of goal achievement into requirements for reclamation, imports of means of production, export of commodities, education, etc. These results can provide a meaningful starting point for a further socio-economic analysis.

As the defined activities include those that have not yet been applied, the model can be used to analyse R & D policy. Do desirable activities require further R & D before they can be applied and is not too much time spent on R & D of techniques that are not selected anyhow? Investments are always needed. Is it possible, however, to formulate policies that stimulate investment in the activities selected by the model and are the credit facilities for the region adequate to meet the investment needs as generated by the model? Another question that could be addressed is whether the educational system is capable of producing the labour qualifications that are indicated by the model.

3 AN ILLUSTRATION OF THE METHOD

3.1 The activities

The method outlined in the previous section was applied to a semi-arid zone in the Mediterranean Basin located in the northern Negev of Israel, in which the agricultural activities consist of sheep husbandry and dryland farming (Tadmor *et al.*, 1974; van Keulen *et al.*, 1982). For the purpose of the analysis, a set of sheep husbandry activities was defined. The set of techniques may encompass up to 200 activities, so that systematic ways to generate them have been developed (Seligman & Spharim, 1987). The activities vary in degree of intensity, ranging from semi-nomadic grazing, with the animals at pasture year-round and only a limited amount of supplementary feeding, to highly intensive systems with the animals kept in a feedlot with no pasture at all. The supplementary feed is composed of concentrates based on imported grain or on locally grown wheat or barley, and on roughages, mainly straw. High quality legume pasture can replace some of the concentrate feed that would be required for ewe and lamb. The higher quality of the legume pasture can be maintained for only part of the year, so replacement can only be partial. All activities are 'target-oriented' in the sense that the yield (kg mutton per ewe per year, or kg grain $ha^{-1} year^{-1}$) defines the input requirements necessary to achieve that yield. Mean input/output values are used to define the activities because target orientation implies that the necessary inputs will be supplied so that annual variation in pasture growth, for instance, will not seriously affect the target. In extensive systems, where input availability is severely limited, the target expectations are set accordingly lower.

The various components of the sheep husbandry systems that are distinguished for the present purpose are given in Table 1. Two types of land are distinguished in the region, cultivable land and rangeland. The cultivable land consists of medium deep to deep loessial soils suitable for arable farming, which can thus be used for natural and improved pasture or for cultivation of wheat or legumes. The rangeland consists of relatively shallow soils overlying parent rock and hence suitable for pasture only. When in pasture, the land can be fenced to save labour.

Depending on system intensity, the ewes are supplemented by either straw as the major component, with a minimum addition of high-quality concentrates, or with concentrates as the major component with a minimum amount of necessary roughage.

There are three sheep breeds in the region: (1) the local fat-tail Awassi, well-adapted to the relatively harsh conditions that may occur in these environments, especially during summer. However, their prolificacy is

TABLE 1

Components of Sheep Husbandry Systems and Coding

1st Character: Land type	
N:	no pasture, feedlot
	Cultivable land, for pasture, wheat and legumes:
U:	unfenced
F:	fenced
	Rangeland, for pasture only:
O:	unfenced
R:	fenced
2nd Character: Supplementary feed	
S:	mainly roughage (wheat straw) as supplementation
C:	mainly concentrate supplementation (imported concentrates, wheat grain, and legume straw)
3rd Character: Sheep breed	
A:	Awassi
I:	Awassi under improved management
M:	Merino
F:	Finn cross
4th Character: Grazing system	
Y:	year-long grazing
D:	grazing deferred in autumn
G:	green season grazing only
N:	no grazing
5th Character: Weaning practice	
N:	normal weaning
E:	early weaning
H:	early weaning applying a labour-saving artificial rearer
6/7th Character: Net lambing rate	
06:	0·6 lambs^{-1} ewe^{-1} year to
24:	2·4 lambs^{-1} ewe^{-1} year

The code OSIYNO7 indicates thus an activity involving Awassi ewes under improved management (I), on unfenced rangeland (O), practising year-long grazing (Y), with mainly roughage as supplementation (S), with normal weaning time (N) and a net lambing rate of 0·7 lambs^{-1} ewe^{-1} year (07).

relatively low even under improved management practices. (2) The German Mutton Merino is the only imported breed that has become established for fat lamb production. With adequate nutrition, its prolificacy is higher than that of the Awassi. (3) Finnish landrace rams have been crossed successfully with both Awassi and Merino ewes for increased prolificacy through more multiple births and shorter lambing cycles. However, lamb mortality tends to be higher and the breed is prone to pulmonary diseases. The cross-breed, therefore, requires more intensive management with increased expense in feed, labour and veterinary care.

Grazing management can substantially affect the performance of the sheep. In the most extensive systems, year-round grazing is practised at stocking rates of up to two sheep per hectare on unfertilized pasture on cultivable land with only a minimum requirement for supplementation during the dry season and around lambing time. Stocking rates of up to 10 ewes per hectare can be maintained on fertilized pasture, provided grazing is deferred after germination of the pasture in autumn, until a critical biomass of around 1000 kg ha^{-1} has been reached (Noy-Meir & Seligman, 1979). In that situation, supplementary feed has to be supplied during the period of deferment. Another alternative is grazing mainly during the green season. This has the advantage that the quality of the material on offer, both in the rainy season and in the beginning of the dry season, is high. The period off-pasture is, however, longer and hence the requirement for supplementary feed is greater.

Weaning of lambs is either at about 115 days of age, at a weaning weight between 20 and 40 kg, depending on system intensity, or at an earlier age at a weight between 15 and 30 kg. In the case of early weaning an artificial rearer may be utilized in highly intensive systems to save labour.

The net lambing rate varies between 0·6 $lambs^{-1}$ ewe^{-1} year in extensive systems to 2·4 $lambs^{-1}$ ewe^{-1} year in highly intensive systems. The most prolific systems include a high proportion of multiple births and three lambing cycles in two years. In those systems supplementary feed requirements are high, both in quantity and in quality.

In the systems on cultivable land nitrogen fertilizer can be applied to increase quantity and quality of the pasture component in the diet. In principle, separate activities can be defined with and without nitrogen fertilizer and the choice can be left to the model, depending on price ratios and other constraints. For the present study, it was assumed that in all intensive systems the pasture was given nitrogen fertilizer while in the more extensive systems that was not the case, and pasture carrying capacity varied accordingly.

Three arable farming activities are defined: continuous wheat, a wheat/fallow rotation and a wheat/legume rotation. In all three activities roughage (straw) and wheat grain are produced while the wheat/legume rotation also produces nutritious late-season pasture that can, to some extent, replace concentrate in the sheep diet. It is assumed that in the continuous wheat system nitrogen fertilizer is always applied, whereas the soil fertility built up in the fallow period is not supplemented by fertilizer in the wheat/fallow system. The leguminous component of the wheat/legume rotation requires phosphorus fertilizer to ensure proper nodulation and effective nitrogen fixation. No nitrogen fertilizer is applied in this rotation.

3.2 The planning horizon

Development is a medium- to long-term process that changes the production and living conditions in a region. This dynamic aspect is fundamental to development and depends largely on the scheduling of investments necessary for the initiation and operation of the specified activities. The investments defined here refer to equipment, fencing material and to investment in the preferred animal breeds. Investments can either originate from the capital generated by the activities and in that way decrease consumptive income, at least in the short run, or money can be borrowed, in which case interest has to be paid and the money must be repaid within the time horizon of the model. For the present study a time horizon of fifteen years was chosen, which is long enough to examine the development pathways selected and not too long for dramatic changes in the technical possibilities to outdate the fund of techniques defined.

3.3 Initial conditions

To delineate the region, both cultivable land with a high production potential and extensive hill range with a low potential, were assumed to occupy 25 000 ha. The initial number of settlers in the region was arbitrarily set at 400. The initial number of ewes was set to 10 000, 2000 and 200 for Awassi, Merino and Finn cross, respectively. The mininum price of hired labour in the region was set at US$ 5000 per person-year.

3.4 The goals

The potentialities of the interactive multiple goal linear programming technique are best utilized if the number of goals specified in the model is initially high and the number of constraints accordingly low. In that way, a high degree of flexibility is achieved and the options for technically feasible development pathways are kept as open as possible (Van Eijk *et al.*, 1986). In the present study only the following goals have been analysed:

— Development aid, i.e. money for imported capital goods that is made available to the region at no cost and does not have to be repaid in the course of development. This goal may be set to zero to investigate the potential of the region to develop on its own. On the other hand, limited amounts of development aid could be allowed, to investigate the possible stimulating effects of such investments.

— Use of imported concentrates. Minimization of this goal could serve the national government when the price of imported concentrates carries a substantial proportion of foreign exchange. However, that also minimizes manure production from concentrates and that may result in increased need for the import of fertilizers, as nutrient deficiency is often a main limiting factor in crop production in semi-arid regions (Van Keulen, 1975; Penning de Vries & Van Keulen, 1982).
— 'Consumption' by the local population is defined as income before taxes. Maximizing consumption is a goal of farmers who operate mainly for profit. It also serves as a tax base for the national government.
— Employment. Maximum employment opportunities are a common planning goal. A distinction should be made between settlers (farmers) in the region for which no alternative employment possibilities exist and the migrant, hired labour that has to be paid. Keeping the number of settlers at a low level and allowing unrestricted hiring and firing of migrant labour may be in the interest of the original population of the region, but maximizing the number of settlers without creating unemployment may be a goal of the government or a settlement agency.
— Traditional system conservation. This goal of maintaining traditional systems and breeds may be motivated by the desire to ensure environmental diversity and conserve animal and plant genetic stock as well as the values that accompany a traditional way of life. Such systems are defined here as those that are based on the local Awassi sheep breed, do not require fencing, mainly use roughage as a supplement and practise year-long grazing.

3.5 The policy views

For the purpose of illustrating the capabilities of the analytical tool, three policy alternatives were formulated:

— The present settlers' view, based on free enterprise. Their goals can be broadly described as: no more settlers, maximize consumption for the present settlers, no limit on the use of hired labour, not more than a minimum area under traditional systems (set here at 10% over the 15-year time horizon), and no limits on the use of imported concentrates.
— The view of a settlement agency. Its goals include: maximum number of settlers with an income at least equal to that of the price of hired labour, low periodic unemployment, not more than a minimum area under traditional systems (10%) and no limits on the use of imported concentrates.

— The view of traditionalists. Their goals could be: minimum use of concentrates, the area under traditional systems as large as possible, a reasonable number of settlers in the region, with an income at least equal to the price of hired labour and limited use of hired labour.

3.6 Results

The extreme attainable value for each of the goals was determined in turn while the requirements on the other goals were either set at their least constraining physical limits or at a very modest level. In this way the highest value that can possibly be achieved for each goal and the lowest value that need be accepted are defined. After this round it was decided that the region had sufficient potential to develop without external investment, so development aid was set to zero. Moreover, the consumptive income before taxes necessary for the population was considered to be at least \$50 million, which is equal to some average number of settlers over the fifteen-year time horizon times the annual costs of hired labour. This value was thus introduced as a lower bound. Subsequently, the model was re-run for three goals that reflect the policy views defined above: consumptive income, employment and the area under traditional systems. The results of those runs are presented in Table 2. In the run where consumptive income is maximized, a total consumption of \$197 million is achieved. This is the maximum value that can be achieved in the region under the specified economic environment. When the two other goals are optimized, the consumptive income drops to \$50 million, the lower bound set by the model. When employment is maximized, a total of 19 200 person-years over the time horizon of fifteen years is achieved, whereas in the run where the area

TABLE 2

Upper and Lower Limits over a Fifteen-year Time Period for Three Goal Variables as Determined in the First Iteration Round of MGLP

Goal maximized	*Values of goal variables*		
	Cons. income (10^6 \$)	*Employment* (10^2 *pers. year*)	*Traditional systems* (10^3 *ha*)
Cons. income	197[b]	135	112
Employment	50[c]	192[b]	100[a]
Traditional systems	50[c]	58[a]	742[b]

[a] Lower limit.
[b] Upper limit.
[c] Lower bound.

under traditional systems is maximized, employment for the total period is equal to only 5800 person-years. This is the minimum that need be accepted in the present study. The run in which the area under traditional systems is maximized indicates that a total of 742 000 ha years over the time horizon of fifteen years out of the physical maximum of 750 000 ha years can be exploited in that way. The requirement that the consumptive income be at least $50 million prevents complete exploitation of the land by traditional systems. When employment is maximized 100 000 ha years of traditional systems are accommodated. This therefore is the lowest value that need be accepted.

The results presented in Table 2 define thus the solution space for the region in the absence of development aid. The traditionalist considered both the consumptive income of $50 million and the employment of 5800 person-years too low, and to improve his bargaining position, was prepared to accept a decrease in the area under traditional systems to 80% of the total. Hence, that requirement was introduced in the model as a lower limit for traditional systems and both consumptive income and employment were maximized again. The results, summarized in Table 3, show that under the requirements of at least 600 000 ha years of traditional systems, consumptive income is in the range of $90 million to $144 million, and employment between 11 300 and 13 100 person-years. The traditionalist, considering these results, preferred a somewhat higher employment than the minimum value in Table 3 and proposed a total of 12 500 person-years. Setting that value as a lower bound and optimizing consumptive income yielded the results given in Table 4. In the traditionalists' world, the region would thus be endowed with a consumptive income of $135 million and an employment of 12 500 person-years which implies an income before taxes about double that of hired labour. Of course, that is entirely his view and it may be challenged by others who could argue that in choosing this

TABLE 3
Results of the Second Round of Iterations, Serving the Traditionalist

Goal maximized	*Values of goal variables*		
	Cons. income (10^6 $)	*Employment* 10^2 *pers. year*	*Traditional systems* (10^3 *ha*)
Cons. income	144[a]	113[b]	600[c]
Employment	90[b]	131[a]	600[c]

[a] Upper limit.
[b] Lower limit.
[c] Lower bound.

TABLE 4
Results of the Final Iteration Round for the Traditionalist

Goal maximized	*Values of goal variables*		
	Cons. income (10^6 \$)	*Employment* (10^2 *pers. year*)	*Traditional systems* (10^3 *ha*)
Cons. income	135[a]	125[b]	600[b]

[a] Upper limit.
[b] Lower bound.

development, he sacrificed too much employment or too much consumptive income in favour of the traditional systems.

A more detailed example has been worked out, where the consequences of various policy options for the systems selected and the output of the region have been analysed. Again the three policy views elaborated in the previous paragraph have been chosen for the illustration, but some additional constraints or requirements have been added to the model, as summarized in Table 5.

Development aid was set to zero in all three scenarios, it being found that the region could very well develop on its own resources. As described previously, the traditionalist requires at least 80% of the area to be used for traditional systems, whereas the settlement agency and the original settlers are satisfied with only 10%. As the requirement is defined for the sum over the total time horizon, year-to-year variation may occur. The use of imported concentrates is not restricted in the policy views of the settlement agency and the original settlers, but is not permitted in the view of the traditionalist. Finally, hired labour is restricted to 200 person-years for the settlement agency and is not restricted in the policy of the traditionalist and the original settlers.

The results in Table 5 show that total employment varies from 15 000 person-years to 10 600 person-years over the 15-year period. The settlers' view results in the lowest total employment, but as the total number of settlers was not allowed to increase, it also required the largest quantity of hired labour. Total consumptive income was intermediate, but because of the small number of settlers the per capita income is by far the highest.

The plan in accordance with the settlement agencies view leads to the highest total employment, and to the highest growth rate of settlers in the area. Total consumptive income is also highest here, but because of the large increase in the number of settlers (almost 20% in the first years!) the per capita income is only half of that achieved by the policy view of the original

TABLE 5
Summary of Results of the MGLP Model for Three Policy Views, and the Limiting Goal Values Imposed

		Traditionalist	*Settlement agency*	*Settlers*	*Unit*
Bounds on the goals					
Development aid	=	0	0	0	\$ year^{-1}
Extensive systems	≥	600	75	75	10^3 ha
Imported concentrates	=	0	free	free	kg
Hired labour	≤	free	200	free	p. year
Results					
Employment		13 000	15 000	10 600	p. year
Settlers		11 740	14 800	6 000	p. year
Linear growth rate settlers		43	74	0	p. year year^{-1}
Hired labour		1 260	200	4 600	p. year
Consumptive income		121	196	169	10^6 \$
Consumptive income/settler		11	14	28	10^3 \$ year^{-1}
Average results for years 7–12					
Sale mutton local market		5·5	9·7	9·1	10^6 kg
Sale mutton for export		0·0	1·5	0·7	10^6 kg
Sale wheat for export		0·0	11·3	15·2	10^6 kg
Imported concentrates		0·0	33·6	30·1	10^6 kg
Intermediate use wheat		13·4	7·7	0·2	10^6 kg
Roughage (straw)		8·9	11·2	8·0	10^6 kg
Nitrogen fertilizer use		1 600	650	608	10^3 kg
Phosphorus fertilizer use		243	866	643	10^3 kg
Area wheat/fallow		0	0	0	ha
Area wheat/wheat		8 400	3 700	100	ha
Area wheat/legume		851	15 100	16 900	ha
Total area wheat		9 251	18 800	17 000	ha
Area extensive systems		60	12	8·25	10^3 ha
Total concentrate use (imported conc., wheat grain, legume straw)		104	359	327	kg ewe^{-1}
Investments		1·9	2·1	4·3	10^6 \$

settlers. It is, however, before taxes, still almost three times as high the minimum of \$5000 per annum for hired labour.

The traditionalist plan leads to an intermediate level of employment, with a smaller increase in the local population. Both total consumptive income and per capita income are the lowest, but the latter is still almost double the minimum for hired labour.

Mutton production from the region is the highest for the policy advocated by the settlement agency, amounting to 11·2 million kg year^{-1} for the period from 7–12 years. This period has been chosen to avoid distortions due to initialization and termination artefacts. Both the settlers' policy and that of the settlement agency require export of mutton outside the region, as the local market cannot absorb the total production. The exported mutton is sold for a lower price than that obtained on the local market. The traditionalists' policy results in the lowest mutton production, as is to be expected in the absence of imported concentrates. However, that restriction is partly compensated by the use of locally produced grain, a practice less favoured in the other two scenarios, as the price of imported concentrates is lower than the export price of wheat.

A somewhat unexpected result of the model is the high level of nitrogen fertilizer use required by the traditionalists' plan. This occurred because restricted use of nitrogen fertilizer was not considered a goal of the traditionalist.

The wheat/fallow rotation is never selected by the model. It is also a relatively uncommon practice in the region, but is sometimes used for phytosanitary reasons. Wheat/wheat is heavily selected in the traditionalists' plan to produce higher amounts of grain to compensate for the restriction on the import of forage grains. This also requires substantial amounts of nitrogen fertilizer. The wheat/legume rotation is prominently present in the runs exploring the policies of the settlement agency and the settlers, apparently as it reduces the dependence on expensive imported concentrate and fertilizer and so increases income for consumption. This is an explicit goal for the settlers and an implicit one for the settlement agency since it provides a minimum livelihood for a greater number of people.

The last line of Table 5 specifies the investments that are needed averaged for the period years 7–12. The lowest investment is necessary to achieve the development path favoured by the traditionalist, mainly because the requirement for a large area under traditional systems leads to animal husbandry systems on unfenced land. Hence, no investment in fencing material is needed. Moreover, the total wheat area is much lower, so that the investment need in capital goods associated with cultivation of wheat is also less. By far the highest investment needs are associated with the development plan favoured by the original settlers. These needs are associated with labour-saving fences, building of physical structures and equipment acquisition on both the rangeland and the cultivable land.

The various sheep husbandry systems selected by the model under the three policy options are summarized in Table 6, again as averages for the 7–12 year period. In the traditionalist plan, Awassi under improved management is by far the most favoured sheep activity. All systems are on unfenced land, while feedlot operations are only minimally selected. The sheep breed selection for the settlement agency and the settlers is very

TABLE 6
Sheep Husbandry Systems Selected, Average of Years 7–12 (For explanation of acronyms see Table 1)

Code	*Traditionalist*	*Settlement agency*	*Settlers (ewe eq.)*
OSIYN07	4 600	0	0
OSIYN09	22 700	13 000	8 200
OSMDE16	0	17 300	320
Total rangeland unfenced	27 300	30 300	8 520
RCIYN09	0	700	4 100
RCMDN14	0	0	5 700
RCMDE16	0	0	13 200
Total rangeland fenced	0	700	23 000
USIYN09	84 800	0	0
UCIYN09	0	16 400	3 300
USIGN10	10 000	0	0
UCIGN10	0	3 200	0
UCMDE16	0	2 400	0
USMGN17	15 100	0	0
UCMGE19	0	21 200	0
USFGN20	8	0	0
Total cultivated land unfenced	109 908	43 200	3 300
FCIYN09	0	2 000	19 700
FCIGN10	0	7 400	0
FCMDN14	0	0	11 300
FCMDE16	0	3 100	3 900
FCMGN17	0	0	4 000
FCMGE19	0	3 350	21 700
FCFGE24	0	0	3 300
Total cultivated land fenced	0	15 850	63 900
NSMN17	83	0	0
NCMNE19	0	27 950	10 400
NSFNN20	2	0	0
NCFNE24	0	27 150	23 800
Total number pasture/feedlot	85	55 100	34 200
Total number of sheep of various breeds			
Awassi systems	0	0	0
Improved Awassi systems	122 300	42 700	35 300
Merino systems	15 100	75 300	70 500
Finn cross systems	10	27 200	27 100
Total number of sheep	137 410	145 200	132 900

similar, with slightly over half of the animals Merinos and slightly more Awassis under improved management than Finn cross. The number of Finn cross ewes in the present runs is restricted by the low initial number that was assumed in the model. The biological reproduction rate is therefore the major constraint for expansion of the activities involving Finn cross. Further analysis is necessary to determine whether higher initial numbers would result in significantly different development patterns in the region.

The largest difference between the settlement agency's view and that of the original settlers is that the latter practise most of their sheep activities on fenced land, while the former favour activities on unfenced land. That is a direct consequence of the differences in labour requirements and employment requirements. Labour requirements are substantially lower when the land is fenced and much of the tedious herding is not necessary. Hence, where population growth is a goal and low unemployment aimed at, systems on unfenced land are preferable. Whether the settlers would be satisfied to work mainly as herders is another question that must be considered in finalizing the development plan. Finally, feedlot operations are selected to a higher degree under the settlement agencies plan, mainly because the feedlots are, in general, relatively labour-intensive activities.

4 EPILOGUE

The interactive multiple goal linear programming technique can help to decide cn feasible development pathways within a wide range of technical and socio-economic scenarios. In that way a gaming procedure can be developed to answer numerous 'what if' questions, like: If these are the constraints and prices, what are the implications for different development policies? When applied to a Mediterranean agropastoral region, the approach produced development pathways that reflected the different viewpoints in a meaningful way. These pathways clearly illustrated the costs of emphasizing one goal in terms of the sacrifices demanded of the other goals. Such quantification of the trade-off between goals is not only valuable in itself, in that it focuses on the wider implications that flow from the possible implementation of a particular viewpoint, but it also serves as a basis for compromise. By iterative adjustment of the various goal requirements, a wider consensus may be attained and a more equitable development policy can be developed, that explicitly accounts for the demands of the various interest groups.

The validity of the exercise depends on the precision of the input/output coefficients; on the appropriateness of the scenario framework that expresses the interaction between activities; and on the proper definition of the goal variables. The problem of goal definition was illustrated by the 'traditionalist' viewpoint, which can be defined in different ways. If it is defined mainly by the type of livestock, then the result can be heavy input of nitrogen fertilizer, as in our analysis.

Another goal of traditionalists may be minimizing fertilizer use, but it appeared that investigation of the consequences of such a goal would require the formulation of additional low-input activities. This is an example of the experience that during the initial phase of model construction, all the demands that may be put on the region by specific users were not foreseen. It may then turn out to be necessary to execute a second round of iterations on the basis of an extended input–output matrix, that accommodates the goals that may be pursued by different interest groups more satisfactorily.

The results of the analysis can be used in a dialogue with policy makers and decision makers to point to the consequences of certain decisions for the possible development pathways of a region and to measures that may be needed to bring about or stimulate the desired pathway. In that way, the planning and implementation processes can be integrated into a consistent framework so as to achieve wider attainment of desirable socio-economic goals in a developing agricultural region.

What precisely is the function of an analysis of the type discussed here in the evolution of development policy and at whom is it aimed? Listing what can and what cannot be expected from such an analysis may help to crystallize an answer to these questions. The most important characteristic of this model is its ability to marshal a large amount of general and local knowledge about actual and potential production systems, regional physical and socio-economic constraints as well as prices of inputs and outputs, and use that information to indicate how available resources can be harnessed to serve different development goals in any set of economic circumstances. The approach employed helps to solve a difficult problem that faces an analyst of future development possibilities: how to distinguish between technical possibilities and behavioural factors that strongly influence policy. The solution is based on a separation between fairly stable quantifiable characteristics of a region and the fund of techniques on the one hand and, on the other hand, the unpredictable and largely unquantifiable behavioural aspects that govern the trade-offs that are reflected in different development pathways. The first are incorporated in the model, but no attempt is made to quantify the more elusive behavioural relations. This creates the necessary freedom that is needed for the optimizing exercises, the room for manoeuver between different approaches and the means with which to analyse the development implications of different viewpoints. In this way it is possible to explore 'margins for policy' and so channel discussion of development into unambiguous terms that can easily be communicated.

Another important characteristic of the model is that it can be used to estimate the importance and specific ability of innovative techniques and production systems to advance the goals that are imposed on a region. This aspect is introduced through the definition of innovative techniques that may or may not have been proven in practice. If activities that are speculative are shown to be important in advancing certain goals, it is then possible to define and justify further research that is necessary to test, develop and implement these speculative techniques.

Hopefully, the analysis serves the inhabitants of the region which is being considered for development. But in a more active sense, it should serve development planners to distinguish between different development pathways. It could also serve to integrate policy makers into the development process so that not only are the implications to goal attainment of any policy made more transparent, but the techniques of implementation are also indicated in practical terms. In this way, communication between politics and planning can become more constructive and the function of research in furthering the development goals can become more efficient.

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